Bulletin of the Seismological Society of America. Vol. 53, No. 5, pp. 905–919. October, 1963

SOURCE-MECHANISM FROM SPECTRA OF LONG-PERIOD SEISMIC SURFACE WAVES. 3. THE ALASKA EARTHQUAKE OF JULY 10, 1958

By Ari Ben-Menahem and M. Nafi Toksöz

ABSTRACT

Source-mechanism is derived from amplitude and phase spectra of mantle Love and Rayleigh waves of the Alaska earthquake of July 10, 1958. The signals R_2, R_3, G_2, G_4, G_5 recorded on the Gilman 80–90 and the Press-Ewing 30–90 seismograph systems at Pasadena, California, are separated, digitized, filtered and Fourier-analyzed. An agreement between theory and observations is obtained for a unilateral fault of 300–350 km, which ruptured with a speed of 3–3.5 km/sec in the direction N40°W. Fault length is in good agreement with the extent of aftershock distribution in the month of July, 1958, and the time of rupture checks with the duration of an impressive T-phase recorded at Hawaii. The phases of the signals are corrected for propagation, instrumental shift and the source finiteness. Initial phases thus obtained agree on a mechanism of a right double-couple with a unit step-function in time.

Introduction

In previous work (Ben-Menahem and Toksöz, 1962, 1963), the source mechanism of two major earthquakes were obtained from the Fourier spectra of Rayleigh and G waves recorded at Pasadena, California. In the present paper we use the same data analysis procedure on a somewhat smaller shock recorded at Pasadena, California. The theoretical background of the methods which were employed for this purpose, are described in earlier publications.

The Alaska earthquake occurred on July 10, 1958, at 06:15:52 GCT at the initial epicenter 58°20′N 136°55′W (Stauder, 1960). It was given a Richter magnitude of $7\frac{3}{4}$–8. Extensive field investigations (Tocher, 1960; Davis and Sanders, 1960) revealed a strike-slip movement over a total distance of 200 km along the Fairweather fault from Nunatak Fiord to Palma Bay, Southeast Alaska. The average strike of the visible trace was N 38°W. Macroseismic evidence, such as reported from Cap Yakataga (Davis and Sanders, 1960) 330 km NW of Lituya Bay, suggests that the actual fault movement extended beyond the reported trace of 200 kilometers.

Stauder (1960) studied initial P motions from 131 stations to obtain a fault plane solution. There is a difference of 15° between his solution and the trend of the observed surface faulting, and a difference of about 8° between the solution and an observed dip of 78°–81 degrees. Knopoff's solution (1961), as obtained by machine calculations, yields a strike of N 21.3°W $\pm$ 2.6 and a dip of 66.6°NE $\pm$ 2.4°. Utsu (1962) found an after-shock area extent of about 350 km, from the distribution of P-S time intervals at Sitka. Brune (1961, 1962) studied the source mechanism of the Alaska earthquake from Mantle Rayleigh waves in the period range $150 < T < 225$ sec as recorded on a net of 12 IGY stations. From the azimuthal distribution of the average time domain amplitudes and initial phases, he concluded that the fault model is that of a right lateral couple which acted as a unit step function in time, and traveled from the epicenter northwestward along the strike of the fault (N 40°W) for 200 km with a velocity of 3 km/sec. The Love-wave phase velocities for the great circles Alaska-Pasadena and Alaska-Wilkes were given by Toksöz and Ben-Menahem (1963). The Rayleigh-wave phase velocities for various great-circle paths through the epicenter of the Alaska earthquake were given by Brune (1961). Attenuation coefficients of Love waves over the Pasadena-Alaska great circle were computed by Ben-Menahem and Toksöz (1963). Båth (1959) reported observations on ultra-long period waves from the Alaska earthquake recorded at Uppsala, Sweden.

Data Analysis

The list of the phases used in the analysis are given in table I. Each wave-train was digitized at 2 second intervals and Fourier analyzed on the IBM 7090 electronic computer. Before the analysis, the data were filtered with a low-pass digital filter. In table I, t_n is the time delay of the window onset with respect to the time of origin.

TABLE I

List of Signals and Pertinent Data

Signal	Seismo-graph System	Com-ponent	Distance Traveled km	Onset of Wave h m s	t_n, sec	Group Velocity Window km/sec		Record Length sec
						Begin	End	
R_2	80–90	Z	36991	08 54 17	9505	3.89	3.47	1138
R_3	80–90	Z	43041	09 20 05	11053	3.89	3.45	1440
G_2	30–90	EW	36991	08 35 05	8351	4.43	4.10	682
G_2	30–90	NS	36991	08 33 05	8231	4.49	4.22	540
G_4	30–90	EW	77007	11 04 06	17294	4.45	4.28	670
G_4	80–90	NS	77007	11 06 05	17413	4.42	4.29	502
G_5	30–90	EW	83057	11 28 41	18769	4.42	4.24	780

Pasadena coordinates 34°08′54″N 118°10′18″W
Epicentral distance 3025 km
Circumference of normal section 40016 km
Central angle 27.22°
Azimuth to epicenter 338.24°
Azimuth from epicenter 144.40°

The source-station geometry is shown in figure 1. The original record of the Pasadena EW 30–90 is shown in figure 2. The separated traces of the signals which were used in the analysis are given in figures 3–5. In figs. 6–7 some of the filtered signals are shown. The filter response is shown in figure 8.

Amplitude-Spectra

The theoretical background for the derivation of the source parameters from the ratio of the spectral amplitudes of even and odd order surface waves has been discussed in detail in a previous paper (Ben-Menahem, 1961). Phase velocities and attenuation coefficients for the Alaska earthquake were reported elsewhere (Toksöz and Ben-Menahem, 1963; Ben-Menahem and Toksöz, 1963).

The directivities R_2/R_3 Z and G_4/G_5 EW are shown in fig. 9, for the period range

330 > T > 70 sec. The best fit was obtained for both Love and Rayleigh waves with $b = 350$ km $V = 3.5$ km/sec and $\theta = 176°$. While the fit of the observed and calculated poles is satisfactory there exists a considerable deviation in the region between these poles.

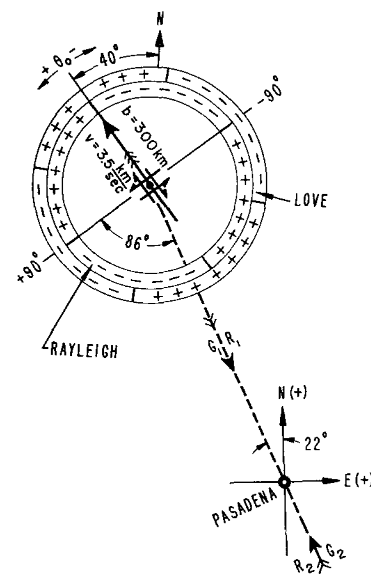

FIG. 1. Position of Pasadena relative to the source of the Alaska earthquake of July 10, 1958

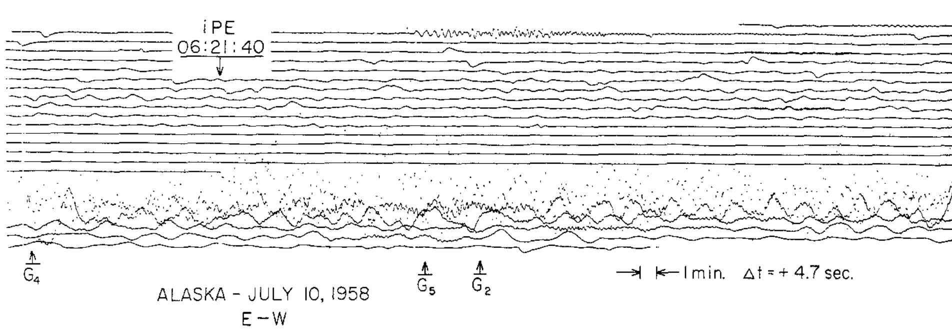

FIG. 2. The Pasadena E-W 30-90 record of the Alaska earthquake of July 10, 1958.

PHASE-SPECTRA

It is shown (Ben-Menahem and Toksöz, 1963) that φ_0, the total initial phase (which is the sum of the phases of the time function, the force system and the source finiteness) is given by

$$\varphi_0 = -\tan^{-1}\left\{\frac{\int_0^\infty F(\tau)\sin\omega\tau\,d\tau}{\int_0^\infty F(\tau)\cos\omega\tau\,d\tau}\right\} + f\left(\frac{\Delta_n}{C} - t_n\right) - \frac{(n-1)}{4} - \varphi_{\text{inst}} + N \qquad n = 1, 2, \cdots \tag{1}$$

Where $F(\tau)$ is the time function of the digitized signal, Δ_n is the distance, C the phase velocity, $(n - 1)/4$ the polar phase shift, and N an integer. Thus the determination of φ_0 requires an accurate knowledge of the phase velocities in the spectral

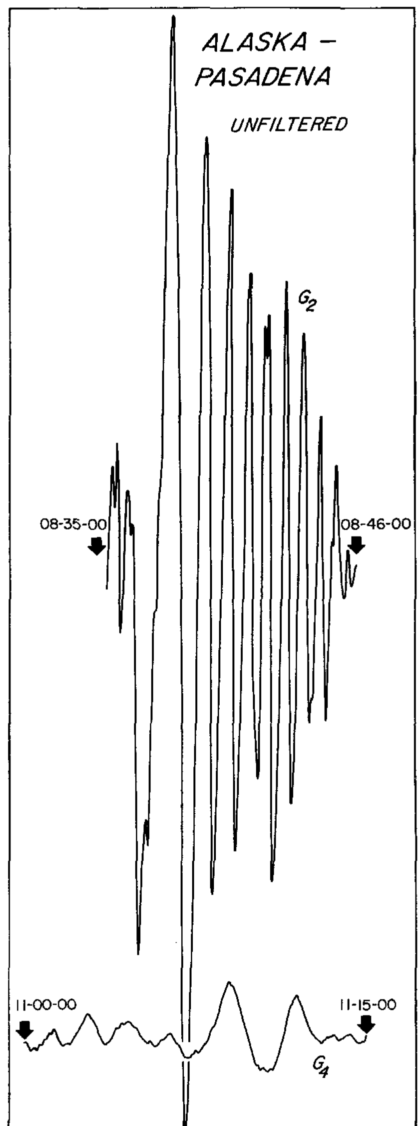

FIG. 3. Unfiltered G_2 and G_4 phases (E-W 30-90) from the Alaska earthquake, recorded at Pasadena.

range of interest. An example for a detailed computation of the propagation phase which is equal to $\varphi_0 + \varphi_{\text{inst}}$ is shown in table II for the signal G_2 EW recorded on the 30–90 seismograph system at Pasadena. Phase velocities are those obtained from G_2–G_4 (Toksöz and Ben-Menahem, 1963). In table III the faultlength is

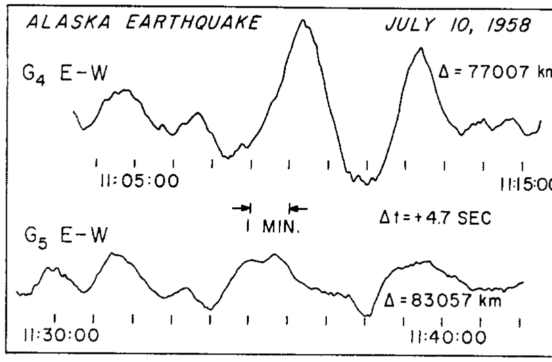

FIG. 4. Unfiltered G_4 and G_5 phases from the Alaska earthquake recorded at Pasadena.

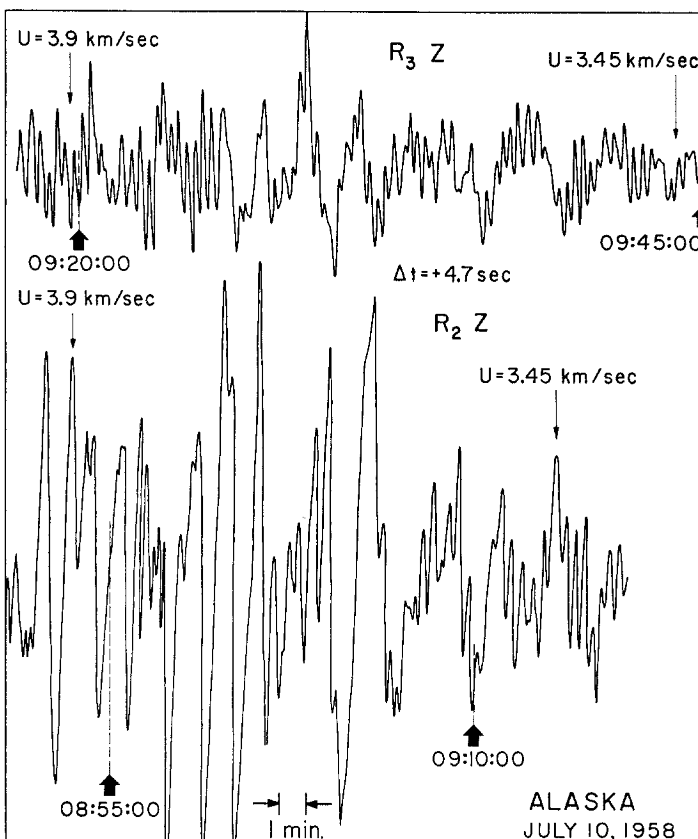

FIG. 5. Unfiltered R_2 and R_3 (Z component) recorded at Pasadena on the Gilman 80–90 seismograph system.

determined from the differential phases of the Z component of Rayleigh waves R_2 and R_3. Since the finiteness phase equals $b/2\lambda((C/V) - \cos\theta_0)$ for R_2 and $b/2\lambda((C/V) + \cos\theta_0)$ for R_3, the differential phase is equal to $b/\lambda \cos\theta_0$. Hence, upon the multiplication of the observed $\delta\varphi_0$ by λ, the value of $b \cos\theta_0$ is obtained.

The average of $b \cos \theta_0$ over the period range $100 < T < 230$ sec, yielded a fault length of about 280 km as compared to 350 km, derived earlier from the amplitudes by the directivity method.

The derivation of the source mechanism is summed up in table IV. Before going into technical details it is useful to describe the general approach briefly. To begin

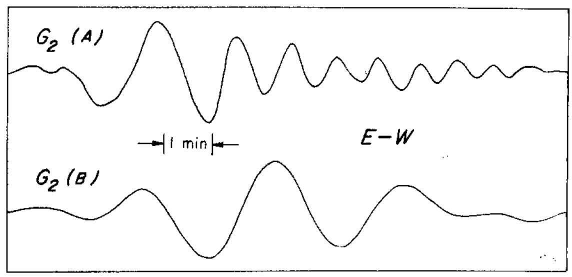

Fig. 6. Mantle Love wave G_2 E-W filtered with two different low pass digital filters: (A) cut-off at $T = 25$ sec, (B) cut-off at $T = 125$ seconds.

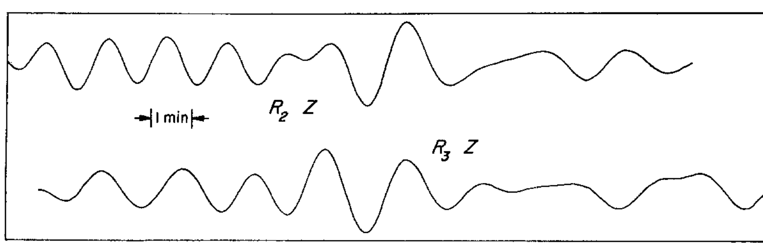

Fig. 7. Mantle Rayleigh waves R_2 and R_3 (80–90 Z) filtered with a low pass digital filter. Amplitude scales are not uniform.

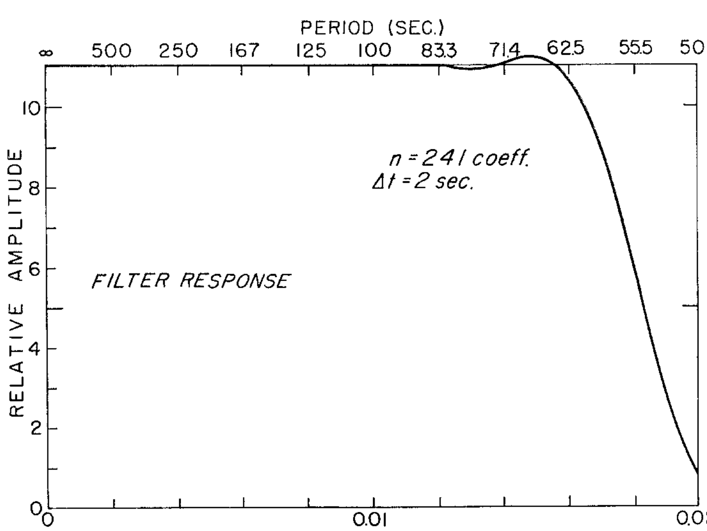

Fig. 8. Response of a digital filter used to eliminate high frequency noise from the digitized signals.

with, one must make a basic assumption that the total phase is the sum of the phase due to the force system at the source (spatial phase) the phase due to the time function at the source (temporal phase) and the phase due to the finite motion of the source (propagation phase).

In table IV the phase $[G_2]$ is corrected for the instrumental phase shift and for finiteness effect. The finiteness correction was computed from the theoretical expression $b/2\lambda((C/V) - \cos\theta_0)$ with the observed average values of $b = 300$ km

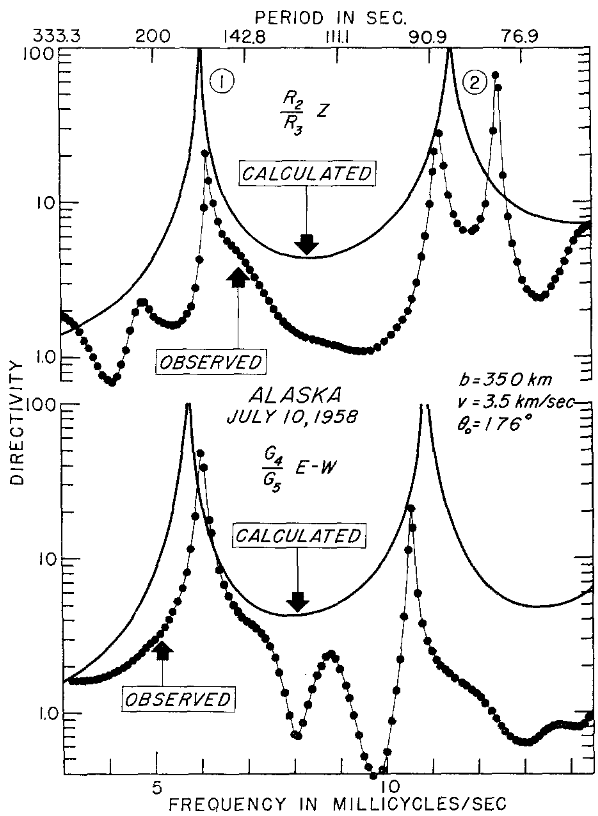

FIG. 9. Observed versus calculated directivity for Mantle Rayleigh waves R_2/R_3 and G_4/G_5 on a semilog scale.

$V = 3.5$ km/sec and $\theta_0 = 176$ degrees. The instrumental correction was computed for a seismometer-galvanometer system in critical damping and zero coupling (Benioff and Gutenberg, 1952; Hagiwara, 1958; Gilman, 1960). The instrumental phase shift for a system of this type is given by:

$$\varphi_{\text{inst}} = \frac{1}{\pi}\left(\tan^{-1}\frac{T}{Tg} + \tan^{-1}\frac{T}{T_s}\right) - \frac{1}{4} \tag{2}$$

where T_g is the period of the galvanometer, T_s is the period of the seismometer. φ_{inst} is measured in parts of circle. A positive value of φ_{inst} means a phase advance of the trace Fourier component with respect to the phase of the ground motion. Equation (2) implies that $\varphi_{\text{inst}} = \frac{3}{4}$ at $T = \infty$ and $\varphi_{\text{inst}} = -\frac{1}{4}$ at $T = 0$. This convention is in agreement with the usual test of the instrument. The instrumental *correction* ($-\varphi_{\text{inst}}$) is tabulated in table IV. Once the phase of the signal is corrected for propagation, finiteness, and instrumental response, the remaining phase consists of the sum of the temporal and spatial phases.

TABLE II

SAMPLE OF DETAILED CALCULATION OF THE PHASE $[G_2] = 3.250 + ((36991/C) - 8351)$—FOURIER PHASE, FOR G_2 EW, ALASKA-PASADENA JULY 10, 1958

f Frequency millicy/sec	c Phase Velocity km/sec	$3.25 + f\left(\frac{36991}{C} - 8351\right)$	The Fourier Integral Phase	$[G_2]$
3.6	5.137	−.890	−.333	−.558
3.8	5.089	−.861	−.333	−.527
4.0	5.047	−.835	−.300	−.535
4.2	5.010	−.813	−.258	−.555
4.4	4.977	−.792	−.214	−.578
4.6	4.948	−.772	−.170	−.602
4.8	4.921	−.752	−.128	−.624
5.0	4.896	−.731	−.088	−.643
5.2	4.874	−.710	−.050	−.660
5.4	4.853	−.686	−.014	−.672
5.6	4.834	−.664	.019	−.683
5.8	4.816	−.640	.051	−.691
6.0	4.800	−.617	.082	−.700
6.2	4.785	−.595	.112	−.707
6.4	4.771	−.573	.142	−.715
6.6	4.758	−.553	.171	−.724
6.8	4.746	−.533	.201	−.734
7.0	4.734	−.513	.231	−.744
7.2	4.724	−.494	.262	−.756
7.4	4.714	−.475	.296	−.771
7.6	4.704	−.455	.331	−.786
7.8	4.695	−.434	.368	−.802
8.0	4.686	−.407	.408	−.816

Phase angle is measured in circles. Phases corrected by π for instrumental directional sign reversal.

Since the temporal phases of all the signals must agree, it is possible to find that particular force configuration which renders equal temporal phases for the analyzed phases of Love and Rayleigh waves. For the Alaska earthquake it was shown (Brune, 1961, 1962) that the time function of the source could be described by the Heaviside unit step function. This implies a constant temporal phase angle equal to $-\pi/2$ (or to -0.250, if measured in circles). To derive the force system we used the phases of G_2, which we considered as best fitted for this purpose. The scheme of computations is described in table IV. The theoretical Love-wave spatial phase for a right double couple is $\cos 2\theta \exp(\pi i/4)$ while that of a right lateral couple is

$\sin^2 \theta \exp(-3\pi i/4)$. The angle θ for the Pasadena-Alaska geodesic was 176°. Therefore, the spatial phase angles of $-3\pi/4$ and $+\pi/4$ are predicted for the cases of couple and double-couple respectively. The results given in table IV show very

TABLE III

DERIVATION OF THE FAULT LENGTH OF THE ALASKA EARTHQUAKE OF JULY 10, 1958 FROM THE DIFFERENTIAL PHASES OF RAYLEIGH WAVES R_2 AND R_3, RECORDED AT PASADENA, CALIFORNIA

f Frequency millicy/sec	T Period sec	$[R_2]$	$[R_3]$	$\delta\varphi = [R_3] - [R_2]$	λ km	$\lambda(\delta\varphi) = b\cos\theta$ km
4.4	227.2	−.384	−.112	.272	1078.9	293
4.6	217.4	−.376	−.077	.299	1018.5	304
4.8	208.3	−.341	−.053	.288	961.4	277
5.0	200.0	−.342	−.050	.292	914.0	267
5.2	192.3	−.319	−.040	.279	868·3	242
5.4	185.1	−.364	−.022	.342	829.8	284
5.6	178.6	−.382	−.029	.353	792.1	280
5.8	172.4	−.351	−.010	.341	759.6	259
6.0	166.6	−.360	−.005	.365	728.7	266
6.2	161.2	−.434	−.025	.409	702.6	287
6.4	156.2	−.407	−.054	.353	674.8	238
6.6	151.5	−.436	−.070	.366	650.0	238
6.8	147.0	−.507	−.097	.410	629.6	258
7.0	142.8	−.543	−.121	.422	610.0	257
7.2	138.9	−.645	−.156	.489	591.2	289
7.4	135.1	−.816	−.351	.465	574.2	267
7.6	131.6	−.909	−.436	.473	557.4	263
7.8	128.2	−.927	−.428	.500	540.1	270
8.0	125.0	−.977	−.454	.523	525.6	274
8.2	121.9	−.956	−.400	.556	510.7	284
8.4	119.0	−.913	−.322	.591	496.5	293
8.6	116.2	−.926	−.306	.620	483.5	300
8.8	113.6	−1.038	−.404	.634	471.7	300
9.0	111.1	−.985	−.315	.670	459.6	308
9.2	108.6	−1.093	−.419	.674	448.9	302
9.4	106.3	−1.108	−.422	.686	438.3	300
9.6	104.1	−1.123	−.431	.692	428.2	296
9.8	102.0	−1.096	−.388	.708	418.5	296
10.0	100.0	−1.070	−.366	.704	409.3	288
					Average	279

clearly that a force system of the single couple type does not agree with a temporal phase of −0.250, while a correction of −0.125 leaves residuals that confirm Brune's findings. The force system was given in figure 1. The inner ring in this figure describes the quadrant distribution $\sin 2\theta$ appropriate for the Rayleigh wave radiation from a right lateral couple or a right double couple, whereas the outer ring gives the distribution $\cos 2\theta$ corresponding to the Love wave radiation from a right double couple. Previous evidence for the occurrence of the double-couple mecha-

TABLE IV

DERIVATION OF THE TEMPORAL PHASE FUNCTION OF THE ALASKA EARTHQUAKE OF JULY 10, 1958 FROM THE ABSOLUTE PHASES OF G_2 E-W RECORDED ON THE 30–90 SEISMOGRAPH AT PASADENA, CALIFORNIA

f Frequency in millicy/sec.	T Period in sec.	$[G_2]$	Corrections			The Resulting Temporal Phase
			Instrument	Finiteness	Force system	
3.6	277.7	−.558	−.616	.058		−.241
3.8	263.1	−.527	−.609	.060		−.201
4.0	250	−.535	−.602	.062		−.200
4.2	238.1	−.555	−.595	.064		−.211
4.4	227.1	−.578	−.588	.066		−.225
4.6	217.4	−.602	−.581	.068		−.240
4.8	208.3	−.624	−.574	.070		−.253
5.0	200	−.643	−.568	.072		−.264
5.2	192.3	−.660	−.561	.074		−.272
5.4	185.1	−.672	−.555	.076		−.276
5.6	178.6	−.683	−.548	.078	−0.125	−.278
5.8	172.4	−.691	−.542	.080		−.278
6.0	166.6	−.700	−.536	.082		−.279
6.2	161.2	−.707	−.529	.084		−.277
6.4	156.2	−.715	−.523	.086		−.277
6.6	151.5	−.724	−.517	.088		−.278
6.8	147.0	−.734	−.511	.090		−.280
7.0	142.8	−.744	−.505	.092		−.282
7.2	138.9	−.756	−.500	.094		−.287
7.4	135.1	−.771	−.493	.096		−.293
7.6	131.6	−.786	−.487	.098		−.300
7.8	128.2	−.802	−.482	.100		−.300
8.0	125	−.816	−.476	.102		−.315
8.2	121.9	−.724	−.471	.104		−.216
8.4	119.0	−.737	−.465	.106		−.221
8.6	116.2	−.730	−.460	.108		−.207
8.8	113.6	−.745	−.454	.110		−.214
9.0	111.1	−.752	−.450	.112		−.215
9.2	108.6	−.752	−.444	.114		−.207
9.4	106.3	−.760	−.433	.117		−.207
9.6	1.401	−.761	−.434	.118		−.202
9.8	102.0	−.771	−.429	.120		−.205
10.0	100	−.754	−.424	.122		−.181
10.2	98.0	−.763	−.419	.125		−.182
10.4	96.1	−.760	−.414	.127	−0.125	−.174
10.6	94.3	−.772	−.409	.128		−.178
10.8	92.6	−.785	−.405	.131		−.184
11.0	90.9	−.794	−.400	.133		−.186
11.2	89.3	−.801	−.395	.135		−.186
11.4	87.7	−.805	−.391	.137		−.184
11.6	86.2	−.826	−.386	.139		−.198
11.8	84.7	−.842	−.382	.141		−.210
12.0	83.3	−.864	−.377	.143		−.223

nism for some Japanese earthquakes has been produced by H. Honda and his collaborators (Honda 1952, 1962).

In an analysis of this kind, one must pay attention to the sign convention of the source system relative to that of the station-system. Consider for example the G_2 EW signal which was used to determine the force-system at the source. If we adopt the convention that the angles in the source-system are measured positively in the counter-clockwise direction and that east is positive in the station system (this is dictated by the choice of the positive amplitude axis for the Fourier analysis) then one must add an angle of π to the absolute phase of G_2 in order to conform to the convention of the station-system. If the signals were recorded on a

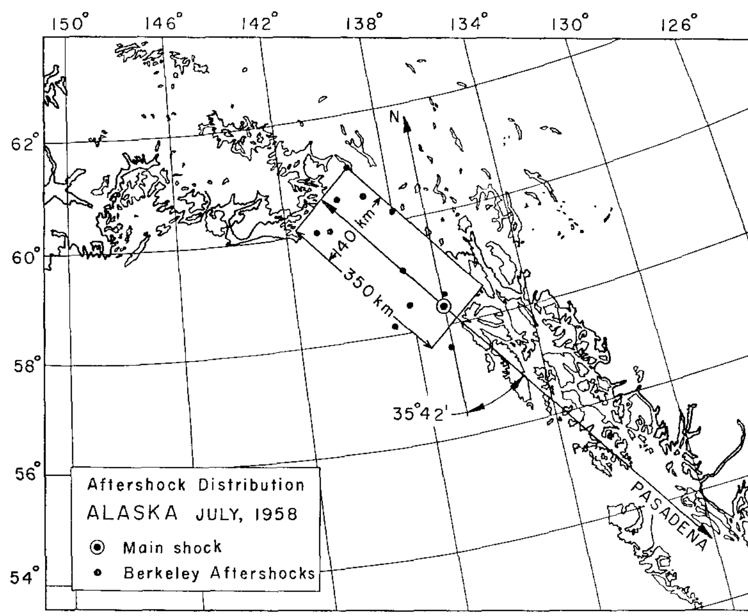

FIG. 10. Aftershock distribution in the month of July 1958 at the source region of the Alaska earthquake.

linear strain seismograph, this correction would not be needed. Similar arguments hold for the horizontal component of the Rayleigh wave.

SUPPORTING EVIDENCE

The aftershock distribution in the month of July 1958 are shown in figure 10. These aftershocks describe an area which probably contributed to the strain-release of the main shock.

An additional check on our results is supplied by the duration of the T-phase as recorded by short period instruments on the islands of Hawaii and Oahu. The use of the T-phase as a measure of the duration of the seismic event at the source has been demonstrated by Eaton, Richter, and Ault (1961) in the case of the Chile earthquake of May 22, 1960.

Figure 11 shows a T-phase recorded at the Hawaiian Volcano Observatory (19°26′N 155°16′W) on a short period instrument. The P wave from the main shock of the Alaska earthquake arrived at this station at 06:23:37 and the T-phase at about 07:06:52. It is found that the initial T arrival traveled a distance of 4565 km with a velocity of $V_T = 1.49$ km/sec. Assuming that the T-phase in this case was caused by a seismic source which moved with an average speed of $V_f = 3$ km/sec over a distance of $b = 300$ km, one obtains a duration at the recording station given by the expression $b/2V_T$ $(\cos\theta + (V_T/V_f))$, where θ is the angle between the fault line and the geodesic passing through the initial epicenter and the station ($\theta = 113°$). This implies that the contribution of the fault's propagation to the duration of the T-phase is around 1.5 min. Additional contributions to the duration may arise from dispersion (Northrop, 1962) and lateral as well as vertical time delays when the conversion to seismic waves takes place at both the trans-

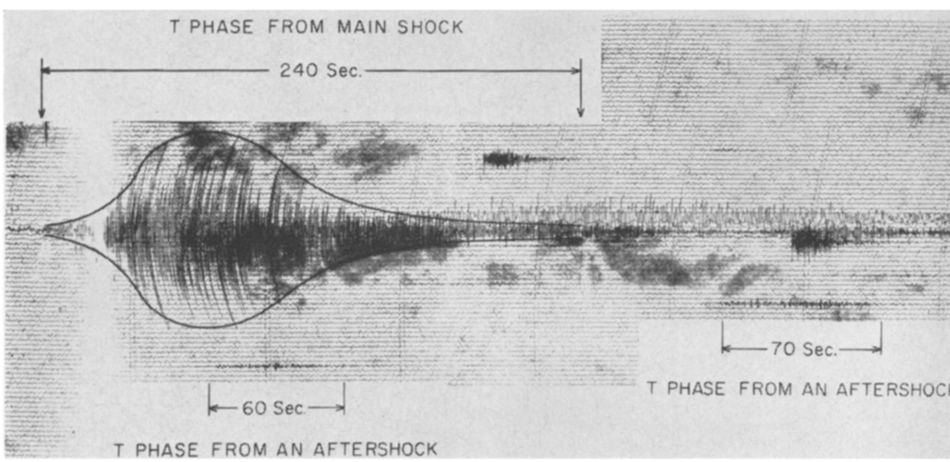

FIG. 11. A short-period smoked paper seismogram of the T-phases from the main shock and two aftershocks of the Alaska earthquake recorded at the HVO, MAUNA LOA, Hawaii.

mission and the reception ends. The derivation of the source parameters from the duration of an observed T-phase is thus hampered by two serious difficulties: First, we are not able to remove the propagation effects from the signal and second, we cannot determine accurately the terminals of the signal on the record because of the microseismic noise level which prevails on most short-period records. The first difficulty may be overcome by a comparison of the T-phase from the main shock to a T-phase from a localized source (both in time and space) at an equivalent epicentral distance. Such a source may be realized by a submarine explosion or an aftershock. Figure 11 shows T-phases from two small aftershocks. The amplitudes of these signals drop down to the ambient noise level in 60–70 seconds. Their durations are apparently shorter than that of the main shock, but no quantitative statement can be obtained.

On May 10, 1962, the seismographs throughout Hawaii recorded a T-phase arriving from the northeast with no detectable P or S phase (J. P. Eaton, private communication). The event has been attributed to a submarine, manmade explosion. From the arrival times of the P and T-phases of this event to Pasadena and Hawaii we were able to estimate the epicenter to be about 3000 km northeast of Hawaii. This point lies approximately on the geodesic from the source of the Alaska earthquake to Hawaii, and both epicentral distances are of the same order. Figure 12 shows a recording of the explosion T-phase at the HVO on the same instrument which recorded the Alaskan earthquake in July 1958. Since both signals have similar amplitudes one may safely compare the duration of the time intervals above the noise level. One then finds that the Alaskan T-phase had a duration of about 4 minutes while the explosion T-phase subsided after about $2\frac{1}{2}$ minutes. The difference between these intervals agrees with the theoretical value of 1.5 minutes obtained

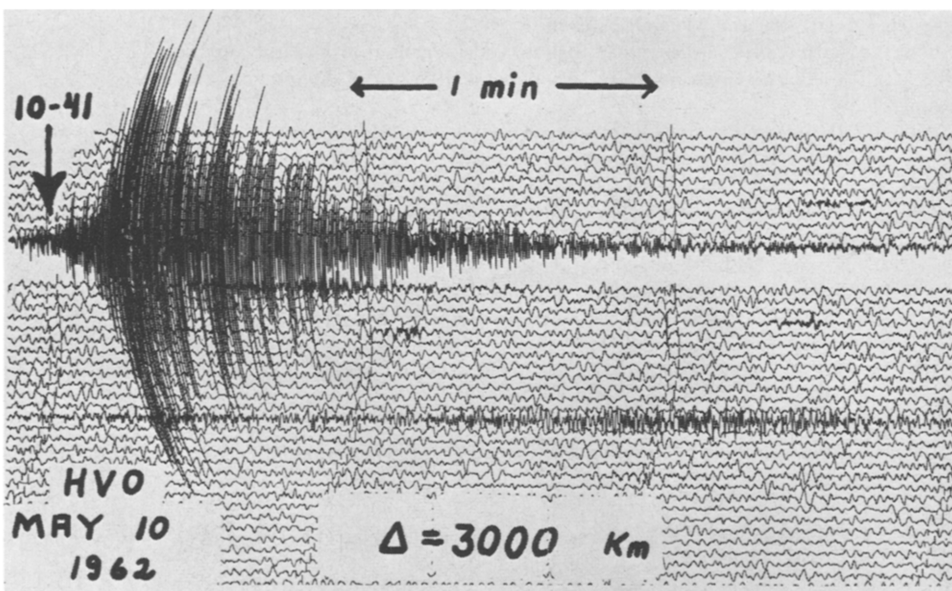

FIG. 12. A short-period smoked paper seismogram of a T-phase of a submarine man-made explosion recorded at the HVO, MAUNA LOA, Hawaii.

earlier on the assumption that the earthquake source propagated over a distance of 300–350 km with a rupture speed of 3–3.5 km/sec.

ACKNOWLEDGMENTS

This research was supported by Grant No. AF-AFOSR-25-63 of the Air Force Office of Scientific Research as part of the Advanced Research Projects Agency project VELA UNIFORM. We wish to express our sincere thanks to Dr. J. P. Eaton and Dr. Harold J. Krivoy of the U.S. Geological Survey and to Dr. Robert A. Earle of the U.S.C.G.S. for sending us the Hawaii T-phase seismograms of the Alaska earthquake.

Acknowledgment is also due to Drs. Keiiti Aki and Augustine Furumoto for helpful discussions. The time series analysis and azimuth-distance computer programs used in the data analysis were written by Dr. Shelton S. Alexander.

References

Båth, M.
1959. "Ultra-Long-Period Motion From the Alaska Earthquake of July 10, 1958," *Geofis. Pura e Applicata*, 41, 91.

Benioff, H., and B. Gutenberg
1952. "The Response of Strain and Pendulum Seismographs to Surface Waves," *Bull. Seism. Soc. Am.*, 43, 229

Ben-Menahem, Ari
1961. "Radiation of Seismic Surface-Waves from Finite Moving Sources," *Bull. Seism. Soc. Am.*, 51, 401.

Ben-Menahem, Ari, and M. Nafi Toksoz
1962. "Source Mechanism from Spectra of Long-Period Seismic Surface-Waves, 1. The Mongolian Earthquake of December 4, 1957," *J. Geophys. Res.*, 67, 1943.

Ben-Menahem, Ari, and M. Nafi Toksoz
1963. "Source Mechanism from Spectra of Long-Period Seismic Surface-Waves. 2. The Kamchatka Earthquake of November 4, 1952," *J. Geophys. Res.* (in press).

Brune, J. N.
1961. "Radiation Pattern of Rayleigh Waves from the Southeast Alaska Earthquake of July 10, 1958," *Publ. Dominion Observatory*, 24, (10) 1.

Brune, J. N.
1962. "Correction of initial Phase Measurements for the Southeast Alaska Earthquake of July 10, 1958, and for Certain Nuclear Explosions," *J. Geophys. Res.*, 67, 3643.

Davis, T. N., and N. K. Sanders
1960. "Alaska Earthquake of July 10, 1958: Intensity distribution and field investigation of Northern Epicentral Region," *Bull. Seism. Soc. Am.*, 50, 221.

Eaton, J. P., D. H. Richter, and W. U. Ault
1961. "The Tsunami of May 23, 1960, on the Island of Hawaii," *Bull. Seism. Soc. Am.*, 51, 135.

Gilman, R.
1960. "Report on Some Experimental Long-Period Seismographs," *Bull. Seism. Soc. Am.*, 50, 553.

Hagiwara, T.
1958. "A Note on the Theory of Electromagnetic Seismograph," *Bull. Earthquake Research Inst.*, 36, 139.

Honda, H., and A. Masatsuka
1952. "On the Mechanisms of the Earthquakes and the Stresses Producing Them in Japan and its Vicinity," Science Reports, *Tokyo Hniv. Ser. 5, Geophys.* 4, 42.

Honda, H.
1962. "Earthquake Mechanism and Seismic Waves," *Geophysical Notes*, Tokyo Univ., 15, (Supplement).

Knopoff, L.
1961. "Statistical Accuracy of the Fault-Plane Problem," *Publ. Dominion Observatory*, 24, (10) 317.

Northrop, J.
1962. "Evidence of Dispersion in Earthquake T-phases," *J. Geophys. Res.*, 67, 2823.

Stauder, W.
1960. "The Alaska Earthquake of July 10, 1958," *Bull. Seism. Soc. Am.*, 50, 293.

Tocher, D.
1960. "The Alaska Earthquake of July 10, 1958," *Bull. Seism. Soc. Am.*, 50, 217–220, 267.

Toksöz, M. N., and A. Ben-Menahem
1963. "Velocities of Mantle Love and Rayleigh Waves Over Multiple Paths," *Bull. Seism. Soc. Am.*, 53, 741.

Utsu, T.
1962. "On the Nature of Three Alaskan Aftershock Sequences of 1957 and 1958," *Bull. Seism. Soc. Am.*, 52, 279.

SEISMOLOGICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

(Division of the Geological Sciences, Contribution No. 1164)

Manuscript received May 31, 1963.